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LIME-FUEL RATIOS OF COMMERCIAL LIME PLANTS IN 1939

BY

FORREST T. MOYER

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LIME-FUEL RATIOS OF COMMERCIAL LIME PLANTS IN 1939[1]

By Forrest T. Moyer[2]

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INTRODUCTION

In conjunction with the statistical survey of the lime industry in 1939, by the Bureau of Mines, producing companies reported the lime-fuel ratios attained in their plants according to type of kiln and kind of fuel. Each ratio, expressed as the number of pounds of lime burned by a unit quantity of fuel, was weighted according to the tonnage of quicklime produced at the reporting plant and grouped with similar data from other plants, so that an average ratio for each type of fuel and kiln could be calculated. By this method the variables that affect ratios of individual plants are more or less equalized, and the computed average lime-fuel ratios provide a fair measure of kiln and fuel efficiencies during 1939.

SCOPE OF REPORT

Commercial sales of lime reported to the Bureau of Mines by producers in 1939 comprised 2,936,295 short tons of quicklime and 1,318,053 short tons of hydrated lime. By reducing the quantity of hydrate to its

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7174."

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approximate weight of contained quicklime (1,035,500 short tons) the total tonnage of quicklime was roughly 3,972,000 short tons; however, this quantity includes 671,561 short tons of refractory (dead-burned) dolomite, which is considered separately in this report because of the higher calcination temperatures used in its production. Eliminating refractory dolomite, the quantity of quicklime sold in 1939 was 3,300,500 short tons. This total includes only the lime sold in competitive markets; it excludes the so-called "captive tonnage" produced by integrated companies as an intermediate material. Although the figures reported by producers represent the quantities of lime sold or used, they are considered here as equivalent to production or kiln output.

Data on fuel ratios were received from producers whose aggregate output of quicklime was roughly 2,400,000 short tons, or slightly less than three-fourths of the total quantity of quicklime made in 1939. Producers of refractory dolomite who supplied data on fuel ratios produced 532,650 short tons of this material, or nearly 80 percent of the total quantity of refractory dolomite sold in 1939.

TYPES OF KILNS

Although limekilns vary greatly in size and design, they may be separated into three general classes: Pot, shaft, and rotary. Pot kilns (vertical, more or less cylindrical types) are charged with a mixed feed of stone and fuel and usually are operated by batches but may be run continuously. They are limited to the solid fuels that have strength enough to support the charge. Shaft (also termed "patent" or "vertical") kilns are large vertical, more or less cylindrical kilns in which the solid and liquid fuels are burned in fireboxes outside the shaft, and only hot gases or gaseous fuels come in contact with the stone in the calcining chamber. These kilns, which are operated continuously, are charged with stone at the top, and the lime is drawn off at the bottom. Rotary kilns are long, nearly horizontal cylinders that revolve slowly. They are operated continuously and are fired with gaseous, liquid, or pulverized solid fuel that is blown into the calcining chamber and burned in contact with the stone.

FUELS

Bituminous coal, which is easily available in many localities at a relatively low price, is the fuel used most widely in the lime industry. It is the only fuel that can be employed in all three types of kilns and was used in burning slightly more than half of the total quicklime and all of the refractory dolomite produced at the plants included in this study. Producer gas, which is made from bituminous coal, ranked next in importance as a fuel in the lime industry. Other fuels are used only in regions where their choice is dictated by occurrence, availability, price, or combinations of all three factors. For example, natural gas is the dominant fuel in the South Central States, wood in the Northwestern States, and fuel oil in California. Upon the basis of the tonnage of lime burned, these fuels rank as follows: Natural gas, wood, coke, fuel oil, and anthracite. Other fuels employed were pitch and a mixture of wood and bituminous coal, but as they were used in only one or two plants no data may be shown concerning them.

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METHODS OF CALCULATION

For plants that reported sales of both quicklime and hydrated lime, the hydrated lime was converted to a quicklime basis. For this conversion the average quicklime equivalents shown by analyses of commercial hydrates were found to be 76 percent of the high-calcium and 82 percent of the dolomitic-lime hydrates.

Average Lime-Fuel Ratios

The fuel ratio of a plant (pounds of lime per unit of fuel) was weighted according to the production of the plant by dividing the ratio into production; this calculation yielded the theoretical quantity of fuel used. For plants reporting more than one ratio because two or more types of kilns or fuels were employed, the total plant production was apportioned among the several sets of factors according to the best information at hand, and the assigned tonnage was used to weight each reported ratio.

After the reported and calculated data on the plants were grouped according to type of kiln and kind of fuel, the aggregage tonnage of quicklime produced by the plants in each group was converted to pounds and divided by the quantity of fuel; thus, an average lime-fuel ratio was obtained for that particular type of kiln when using a certain fuel. These ratios may be used as measures of performance in each particular group.

Thermal Efficiencies

In order to compare the relative effectiveness of the fuels and kilns the thermal efficiency, expressed as the ratio of the heat actually applied to the heat theoretically required to produce a short ton of lime, was computed for each fuel in each type of kiln. The results are approximate because average B. t. u. values were employed for the several fuels, all calculations were made upon a moisture-free basis, and the heat required was calculated for a batch process although only pot kilns are operated in this manner.

The total heat supplied was ascertained by multiplying the quantity of fuel employed by the average B. t. u. value of the fuel. The heat applied per short ton of lime was found by dividing the total supply of heat by the tonnage of quicklime produced.

The theoretical quantity of heat required was calculated in two steps: (1) The heat needed to raise the stone from an average atmospheric temperature (60° F.) to an assumed average maximum temperature of calcination (2,200° F.) and (2) the heat required to dissociate the limestone into lime.

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The reaction that occurs in calcining a chemically pure limestone may be expressed as follows:

$$\text{Limestone} + \text{heat} \rightleftharpoons \text{lime} + \text{carbon dioxide, or}$$

$$CaCO_3 + 43{,}250 \text{ cal.} \overset{3/}{\rightleftharpoons} CaO + CO_2.$$

As 1.786 pounds of limestone are required to produce 1 pound of lime, this weight of limestone multiplied by its specific heat (0.216) and the temperature differential (2,200° - 60° F.) gives 826 B. t. u. as the quantity of heat necessary to raise the temperature of enough stone to produce 1 pound of lime at an average calcination temperature. The dissociation of 1.786 pounds of limestone to 1 pound of lime requires 1,388 B. t. u. Hence, the total theoretical heat needed is 2,214 B. t. u. per pound, or 4,428,000 B. t. u. per short ton of high-calcium lime.

The theoretical heat requirements of refractory (dead-burned) dolomite are calculated similarly. The reaction follows:

$$CaMg(CO_3)_2 + 72{,}900 \text{ cal.} \overset{4/}{\rightleftharpoons} CaOMgO + 2CO_2.$$

The heat needed to raise the temperature of dolomite to an average calcination temperature equals 1.913 pounds (quantity of stone required) times 0.222 (specific heat) times (2,800° - 60° F.) (temperature differential), or 1,164 B. t. u. per pound of refractory dolomite produced. This quantity plus the heat of dissociation of the reaction, which is equivalent to 1,361 B. t. u., equals the total theoretical heat requirement, 2,525 B. t. u. per pound or 5,050,000 B. t. u. per short ton of refractory dolomite produced.

The heat needed to calcine dolomite to dolomitic lime, computed by the foregoing procedure with 2,000° F. as the average maximum temperature of calcination, is 2,185 B. t. u. per pound or 4,370,000 B. t. u. per ton of dolomitic lime. This quantity differs so little from that calculated for high-calcium lime that the latter figure is used throughout the report.

LIME-FUEL RATIOS

Variations in heating values. - As cost per B. t. u. usually is the strongest factor in selecting a fuel, lime producers commonly utilize low-cost local fuels. The unit heating value of certain fuels, such as bituminous coal, varies appreciably in different localities. This diversity in value probably is an important cause of variations in comparable fuel ratios reported by the producing companies. The marked differences in fuel ratios shown in table 1, as attained with bituminous coal in shaft kilns in several localities, probably are due largely to variations in the heating value of the coals employed.

3/ Heat of reaction calculated with data from Bichowsky, F. R., and Rossini, F. D., Thermochemistry of Chemical Substances. Reinhold Publishing Corporation, New York, 1936, pp. 44, 113, 117, 120, 121.

4/ See footnote 3.

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TABLE 1. - Lime-fuel ratios attained in shaft kilns using bituminous coal, by States, in 1939

State	Reporting		Number of kilns	Lime 1/ produced (short tons)	Lime-fuel ratios 2/	
	Operators	Plants			Range reported	Calculated average
Colorado, New Mexico, Utah, Montana.....	5	5	8	9,692	2.50 to 3.85	3.54
Kentucky, Illinois, Missouri.....	4	4	22	96,913	2.50 to 3.00	2.87
Indiana, Michigan.....	5	5	19	44,077	1.47 to 4.25	1.87
New York, Maine, Massachusetts....	4	4	9	22,814	2.00 to 4.00	3.38
Ohio.....	8	10	152	342,680	2.30 to 5.23	3.90
Pennsylvania..	11	12	81	165,152	2.76 to 4.82	3.38
Tennessee.....	6	6	35	77,140	2.00 to 3.00	2.58
Virginia, West Virginia.....	8	8	39	70,554	2.50 to 4.00	3.08

1/ Quantity of quicklime sold plus calculated equivalent quicklime contained in hydrated lime sold from reporting plants in 1939.
2/ Expressed as pounds of lime calcined by 1 pound of bituminous coal.

A noteworthy feature of table 1 is the wide range (from 1.47 to 5.23) in the ratios reported for individual plants. There is a marked correlation between the locations of plants in which ratios were low and areas that contain bituminous coals of low heating value. The only areas in which the average ratios fall below 3 are the Central, or Mississippi Valley, States where the coals have relatively low B. t. u. values. The average ratio is highest in Ohio where large, efficient plants use mainly coals from West Virginia with high heating values.

Relative Importance of Different Fuels

The popularity of bituminous coal for calcining lime is evident from table 2. Indicated consumption of this fuel in reporting plants for direct calcination of lime approximated 400,000 short tons and for making refractory dolomite, about 225,000 tons. In addition, bituminous coal converted to producer gas totaled 125,000 tons, and the tonnage of coke consumed was equivalent to approximately 50,000 short tons of coal. Altogether, the consumption of bituminous coal in reporting plants totaled approximately 800,000 short tons. Other fuels included nearly 4,000 short tons of anthracite, 70,000 cords of wood, 1-1/2 billion cubic feet of natural gas, and 200,000 barrels of fuel oil.

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TABLE 2. - Lime-fuel ratios, by type of kiln and kind of fuel, for reporting plants in 1939

Type of kiln	Kind of fuel	Reporting		Number of kilns	Lime 1/ produced, short tons	Fuel used		Lime-fuel ratio 3/	
		Operators	Plants			Quantity 2/	Unit	Range reported	Calculated average
Pot.....	Anthracite.....	3	3	26	8,880	4,904,000	Pounds	2.55 - 7.00	3.62
	Bituminous coal	5	5	18	10,784	6,024,000	do.	2.50 - 5.00	3.58
	Coke.....	14	15	69	115,275	59,208,000	do.	3.00 - 6.00	3.89
	Wood.....	3	3	6	17,504	8,529	Cords	2,600 - 6,000	4,104.58
Shaft...	Anthracite.....	3	3	4	4,513	2,580,000	Pounds	3.22 - 4.00	3.50
	Bituminous coal	51	54	365	829,022	512,800,000	do.	1.47 - 5.23	3.23
	Coke.....	4	4	15	28,662	12,994,000	do.	3.85 - 8.00	4.41
	Producer gas...	10	10	63	229,191	112,278,000	Pounds of bit. coal	3.10 - 6.00	4.08
	Natural gas....	13	13	37	140,071	925,844	M cu.ft.	257.6 - 472.0	302.58
	Fuel oil.....	4	4	10	18,578	21,627	Barrels	1,500 - 2,350	1,718.04
	Wood.....	20	20	73	153,001	62,045	Cords	2,500 - 8,000	4,931.94
Rotary..	Bituminous coal	11	13	24	485,060	288,098,000	Pounds	2.50 - 4.50	3.37
	Producer gas...	6	6	10	178,945	130,664,000	Pounds of bit. coal	1.50 - 4.21	2.74
	Natural gas....	4	4	6	69,466	554,730	M cu.ft.	200.0 - 320.0	250.45
	Fuel oil.....	9	9	14	116,237	174,188	Barrels	1,000 - 1,600	1,334.62
Refractory (dead-burned) dolomite									
Rotary	Bituminous coal	6	8	23	532,650	459,670,000	Pounds	2.00 - 2.50	2.32

1/ Quantity of quicklime sold plus calculated equivalent quicklime contained in hydrated lime sold from reporting plants during 1939.
2/ Calculated from quicklime production and reported lime-fuel ratios.
3/ Reported and calculated as pounds of lime calcined by a unit quantity of fuel.

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Comparison of Types of Kilns

Pot kilns generally are considered the most efficient type, and this conclusion is verified by the data in table 2. Shaft kilns usually are regarded as more efficient than rotary kilns; but, as shown in the table, the average ratio with bituminous coal is higher in rotary than in shaft kilns. This higher ratio is due partly to the fact that rotary kilns employ coal having a higher average heating value than coals used generally in shaft kilns and partly to recent advances in the design and more efficient operation of rotary kilns.

The wide ranges in reported ratios for each fuel in a kiln of a particular type are due partly to the variable unit heating value of the fuel and, other factors being equal (size and gradation of feed, etc.), partly to differences in age, design, and operating technique of the calcining equipment.

THERMAL EFFICIENCIES

Heat applied to the raw stone to produce a unit quantity of lime varies with several factors. Of these factors, efficiency of the kiln and effectiveness of a fuel in that kiln are controllable only to a limited extent by the operator. Probably some fuels would be more effective in one type of kiln than another, or one fuel may perform more efficiently than another in equipment of the same type, other factors being equal.

Efficiencies in table 3 are the results of calculations based upon reported and theoretical data that attempt to evaluate the relative effectiveness of the different fuels and types of kilns employed in the lime industry in 1939. It should be remembered that "thermal efficiencies" as used in this report are merely relative measures of the effectiveness of different fuels and kilns expressed in terms that permit ready comparison. They are limited as described under Methods of Calculation, and as they do not take into account the heat balances of the calcination process they are higher than they would be if all the heat uses and losses were considered.

Comparison of Fuels

As indicated in table 3, coke used in shaft kilns was more efficient than any other combination of fuel and kiln, although only a relatively small quantity of lime was produced with this combination. A large tonnage of lime was burned in shaft kilns with producer gas, the next most efficient combination. Bituminous coal had the lowest efficiency of the fuels employed in shaft kilns but the highest in rotary kilns. For over-all operation with the fuels used, pot kilns were the most efficient, shaft kilns were next, and rotary kilns were the least efficient. The efficiency of rotary kilns for making refractory dolomite with bituminous coal was considerably lower than for burning lime with the same fuel, as dead burning requires a much higher temperature than calcining to quicklime.

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TABLE 3. - Heat applied and thermal efficiency attained in calcining equipment in lime plants in 1939

Type of kiln	Kind of fuel	Lime 1/ produced, short tons	B. t. u. applied 2/		Thermal 3/ efficiency, percent
			Total, millions	Per ton of lime	
Pot.....	Anthracite.....	8,880	63,752	7,179,000	62
	Bituminous coal...	10,784	78,312	7,262,000	61
	Coke.....	115,275	754,902	6,549,000	68
	Wood.....	17,504	140,729	8,040,000	55
		152,443	1,037,695	6,807,000	65
Shaft.....	Anthracite.....	4,513	33,540	7,432,000	60
	Bituminous coal...	829,022	6,666,400	8,041,000	55
	Coke.....	28,662	165,674	5,780,000	77
	Producer gas.....	229,191	1,459,614	6,369,000	70
	Natural gas.....	140,071	925,844	6,610,000	67
	Fuel oil.....	18,578	129,762	6,985,000	63
	Wood.....	153,001	1,023,743	6,691,000	66
		1,403,038	10,404,577	7,416,000	60
Rotary....	Bituminous coal...	485,060	3,745,274	7,721,000	57
	Producer gas.....	178,945	1,698,632	9,492,000	47
	Natural gas.....	69,466	554,730	7,986,000	55
	Fuel oil.....	116,237	1,045,128	8,991,000	49
		849,708	7,043,764	8,290,000	53
Grand total.....		2,405,189	18,486,036	7,686,000	58
Refractory (dead-burned) dolomite					
Rotary....	Bituminous coal...	532,650	5,975,710	11,219,000	45

1/ Quantity of quicklime sold plus calculated equivalent quicklime contained in hydrated lime sold from reporting plants in 1939.

2/ Unit heat values employed are: Anthracite, 13,000 B. t. u. per pound; bituminous coal, 13,000 B. t. u. per pound; coke, 12,750 B. t. u. per pound; natural gas, 1,000,000 B. t. u. per M cu. ft.; fuel oil, 6,000,000 B. t. u. per barrel; wood, 16,500,000 B. t. u. per cord.

3/ Theoretical quantity of heat required divided by quantity applied. See text.

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